SAFETY OF SPENT FUEL TRANSPORT TO AN INTERNATIONAL REPOSITORY

Kahraman Tunaboylu[1], Anthony Playfair[1] and Neil Chapman[2]
[1]Colenco Power Engineering, CH-5405, Baden, Switzerland
[2]Pangea Resources International, CH-5405, Baden, Switzerland

ABSTRACT

Pangea is evaluating the development of international repositories for long-lived radioactive wastes. A frequently expressed concern is that transport of highly radioactive wastes to an international repository will create unacceptable risks to the public. Over the operational life of a repository, many thousands of tonnes of waste will be shipped across the world, by sea, to the host country. This generic study evaluates the nature and the magnitude of the risks of transporting a model inventory of spent fuel to a Pangea repository and compares them with other risks to which the public is exposed.

INTRODUCTION

Pangea aims to develop international storage and disposal facilities for long-lived waste that could be of particular use to smaller nuclear power programmes, unlikely to build their own repositories. Transport to a repository host country will be by sea, followed by either road or rail transport to the disposal site. Pangea is exploring the 'high-isolation' repository concept, based on exceptionally stable environments in flat, arid regions with no groundwater flow in repository host rock formations. Regions of the world have been identified with appropriate geological, geographical and climate characteristics for a high isolation repository [1]. The majority are in the southern hemisphere. This study uses a hypothetical southern hemisphere repository location and assumes waste-producing countries in Europe and the NW Pacific areas.

REFERENCE SCENARIO

This study, presented in full in [2], adopts a reference scenario which considers the transport only of spent MOX fuel assemblies (SFAs) from PWRs (the majority of nuclear power plants; MOX representing a higher activity inventory for the same burn-up). It is assumed that 33 MOX SFAs with a burn-up of ~36 GWd/tHM are transported in each cask (IAEA Type B Packaging). The reference cask is assumed to be the CASTOR type, which complies with IAEA Transport Regulation requirements [3] for type B(M)F packages. CASTOR (GNB, Hanau, Germany) is a commercially available and well-investigated transport package, already licensed by regulatory authorities in several countries. It is fitted with a double barrier system consisting of a primary and secondary lid with an additional cover plate to protect the leak-tight lids. The sealing system uses metallic and elastomer seals on each lid. In accidents (especially in fires), sealing is guaranteed by the metallic gaskets. The amount of spent fuel that may be received by a Pangea repository is conjectural at this stage. A scenario is considered where 2000 tonnes of fuel are received each year. Transport risks will scale linearly with the amount of fuel shipped. For this generic study, the reference scenario is five shiploads per year, each with 24 type B transport packages, transferred to 5 train shipments (or equivalent number of single truck shipments).

METHODOLOGY

Owing to the extremely low rate of incidents and consequent absence of historical data, probabilistic methods have been applied to provide a conservative assessment of the risks associated with transport operations. The methodology adopted is shown in Figure 1. Statistics for accident rates for land and sea conveyances have been obtained from the literature and accident frequencies established. Frequencies are combined with information on severity and consequences of accidents to estimate the frequency of accidents that could lead to releases of radiaoctivity. Releases of radioactivity can then be calculated from the inventory of a package and the postulated leak rate that is assumed to occur as a result of a beyond-design-basis accident. Using these source terms and models for radiation doses at various distances from the accident, potential radiological exposures can be calculated as effective doses (in mSv) for individuals. They can be converted to risks (latent cancer fatalities, LCF) using the latest ICRP recommended dose to risk conversion factor for members of the public.

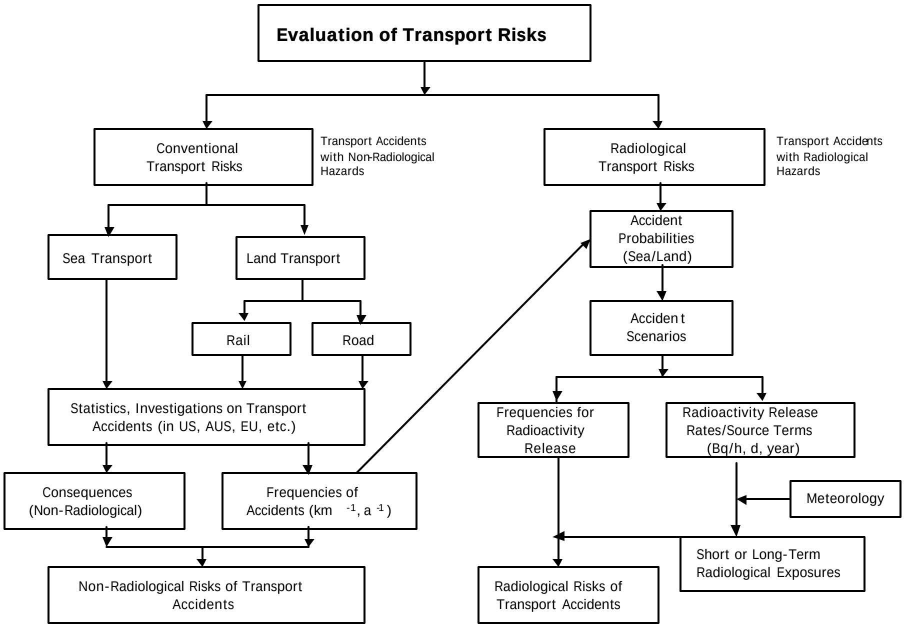

Figure 1: The methodology for the evaluation of transport risks

TRANSPORT ACCIDENT PROBABILITIES (P_{AC})

Table 1 gives the land transport accident frequencies used in this study [4]. A nominal road or rail transport distance of 1,000 km between the receiving port and the Pangea repository is assumed.

Table 1 : Road and Rail Accident Frequencies

Transport Mode	Accident frequency (per -km)	Accident Frequency per Journey (1000 km)
Road (Truck)	3.0×10^{-7}	3.0×10^{-4}
Rail (Train)	2.4×10^{-8}	2.4×10^{-5}

Table 2: Collision frequencies at sea (22,000 km voyage)

Waters	Specific frequency per nmi or port call	Distance travelled (nmi)* or port calls per voyage	Frequency per voyage
In Port	4.0×10^{-5}	2 port calls**	8.0×10^{-5}
English Channel	1.0×10^{-7}	800 (1,530)	8.0×10^{-5}
Coastal Waters	2.0×10^{-7}	1,000 (1,913)	2.0×10^{-4}
Open Ocean	7.0×10^{-9}	9,700 (18,557)	6.8×10^{-5}
Total		11,500 (22,000)	4.3×10^{-4}

* The distances in brackets are in km. ** Two port calls per voyage (at departure and at arrival)

The greatest distances likely to be involved for a sea voyage would be an equivalent distance to that from Europe to Australia via the Cape of Good Hope (22,000 km). Table 2 gives estimated collision frequencies over such a route, based on an IAEA study [5]. Given that a ship collision occurs, the probability of a fire is 0.026. Thus, the frequency of a collision occurring in which a fire also occurs is 1.1×10^{-5} per voyage. These frequencies are considered highly conservative, as they are for all types of shipping and take no account of the stringent quality and safety management systems that surround the construction and operation of vessels carrying radioactive materials.

ACCIDENT SEVERITIES (BK) AND PROBABILITIES (P_{BK})

Accident severities can be categorised according to the mecahnical and thermal loads imparted to a cask. The KONRAD study [6] specifies nine severity categories (BK1-BK9), based on mechanical strains caused by three ranges of impact speed with non-yielding surfaces and three ranges of thermal energy inputs. This categorisation is used here and is shown with the occurrence probabilities in Table 3. Only accidents where the impacts are higher than the design loads can lead to a release of radioactivity (all categories from BK 4 to BK 9). These impact speeds do not correspond directly to those in likely accident situations. The KONRAD categories refer to impacts with non-yielding surfaces. In real accidents there are likely to be damping mechanisms involving yielding surfaces. The IAEA standard nine-metre drop test is equivalent to an impact speed of 50 km/h in the KONRAD scheme. Simulated full-scale accident tests have involved real impact speeds much greater than this, with the casks remaining sealed. A UK test (involving a 140 t train hitting the lid area of a cask at 164 km/h) led to an estimated absorbed kinetic energy that was less than 40% of that involved in the IAEA 50 km/h drop test [7]. Even such severe impacts would thus fall into categories less than BK 4. The KONRAD categories also consider the combined effects of impact and fire. A thirty-minute, fully engulfing fire at 800° is the IAEA standard test for collision accidents accompanied by fire. Such pervasive, sustained temperatures are unlikely in an accident. Accidents in the BK 4 – BK 5 range are thus considered a suitable reference for this study, although they are also considered conservative.

Table 3: Probability of occurrence of severity categories, assuming a truck or rail accident occurs [6].

Impact speed range	Probability of occurrence assuming a truck accident occurs		
	No fire	30 minutes fire, 800°C	60 minutes fire, 800°C
0 - 35 km/h	0.50 (BK 1)	1.05×10^{-2} (BK 2)	8.40×10^{-4} (BK 3)
36 - 80 km/h	0.43 (BK 4)	9.45×10^{-3} (BK 5)	7.56×10^{-4} (BK 6)
Over 80 km/h	0.05 (BK 7)	1.05×10^{-3} (BK 8)	8.40×10^{-5} (BK 9)

Impact speed range	Probability of occurrence assuming a rail accident occurs		
	No fire	30 minutes fire, 800°C	60 minutes fire, 800°C
0 - 35 km/h	0.36 (BK 1)	5.9×10^{-2} (BK 2)	2.9×10^{-2} (BK 3)
36 - 80 km/h	0.45 (BK 4)	9.5×10^{-3} (BK 5)	4.7×10^{-3} (BK 6)
Over 80 km/h	8.4×10^{-2} (BK 7)	1.8×10^{-3} (BK 8)	8.8×10^{-4} (BK 9)

RADIOACTIVITY RELEASES AND THEIR PROBABILITIES

In this study it is assumed that only one shipping cask is damaged by the mechanical and/or thermal loads involved in a severe accident. The probability that a second cask will be damaged is considered to be low enough to be neglected. Even if several casks failed, the releases would only be a factor of a few times higher and would not have a significant impact on the findings. The probability of radioactive release (P_{RR}: see Table 4) is the product of the probability (P_{AC}) that an accident occurs, (e.g. Table 1) and the frequency of occurrence for relevant Severity Categories (Table 3).

Table 4: Probabilities (P_{RR}) of radioactivity release for accidents of severity categories BK 4 and 5

Severity Category	Road		Rail	
	per km	per transport*	per km	per transport*
BK 4	1.3×10^{-7}	1.3×10^{-4}	1.1×10^{-8}	1.1×10^{-5}
BK 5	2.8×10^{-9}	2.8×10^{-6}	2.3×10^{-10}	2.3×10^{-7}

* Transport: 1,000 km land transport (road or rail)

For spent fuel transport accidents, activity release would occur in two successive steps: (i) from fuel rods to the interior of the cask, assuming failure of the fuel rods and (ii) from the cask itself to the environment, assuming a leakage path through the cask closure seal(s). Both the PSE [8] and NUREG studies [9] assume that 50 % of the fuel rods in a cask fail in a side impact to the cask with a speed >50 km/h, which is considered to be very conservative. The CASTOR cask is designed so that, under accident conditions simulated by the IAEA Transport Regulation tests, the leak rate through the double barrier system will not exceed 10^{-7} mbar.l/s. The PSE analysis conservatively considers a leak rate of 10^{-4} mbar.l/s for an accident in which only the outer seals fail and 1 mbar.l/s for failure of both seals. The study calculated release fractions from the cask interior to the external environment over a conservative period of 10 hours for conditions corresponding to accident severity classes BK 4 and 5. Taking into account both 'internal' release and the proportion of this that is then released to the environment, the total release (FR) from a damaged cask can be calculated (Table 5).

Table 5: Total radionuclide specific release fractions (from fuel rods to environment: FR) for a 10 hours release period

Impact speed >50 km/h	**^{3}H**	**^{85}Kr ^{129}I**	**^{134}Cs ^{137}Cs**	**Aerosol particles**
Failure of one seal, no fire	2.0×10^{-7}	4.0×10^{-8}	2.0×10^{-10}	2.0×10^{-14}
With fire (30 min.)	2.8×10^{-7}	5.5×10^{-8}	2.6×10^{-10}	2.6×10^{-14}
Failure of both seals, no fire	2.0×10^{-3}	4.0×10^{-4}	2.0×10^{-6}	2.0×10^{-10}
With fire (30 min.)	2.8×10^{-3}	5.5×10^{-4}	2.6×10^{-6}	2.6×10^{-10}

Radioactivity releases can be calculated from the total radionuclide inventory of a shipping cask and the total release fractions (FR) for each radionuclide. For a CASTOR cask with the radionuclide inventory assumed in this study the maximal releases for a double failure of the sealing system are given in Table 6. These figures are considered to be 1 - 3 orders of magnitude higher than realistically expected due to the assumed conservative fuel rod failure rate (50 % of all rods: a more realistic value would be one to two orders of magnitude less) and the assumed conservative leak rate (1 mbar.l/s) for a double failure of the seal of both lids. Releases are calculated for a conservative period of ten hours. In the highly unlikely situation that the situation were not rectified within 10 hours, radioactivity releases to the environment would still remain within tolerable limits, even during a period of one week following the accident (corresponding to the permissible release limits in the IAEA Transport Regulations, with the only exception being ^{137}Cs).

RADIOLOGICAL CONSEQUENCES OF RELEASES

Calculations of radiological consequences of releases from packages need to take into account release duration, atmospheric conditions and the exposure pathways. This study uses the maximum release rates in Table 6 and the most conservative atmospheric conditions that would lead to the highest exposure. Leakage duration was assumed to be 10 hours, including a 30 minute fire at the beginning of the release after collision. Since people would be expected to be evacuated from the contaminated area, the inhalation portion of dose is the most realistic exposure figure to use. It can be assumed that the release will be stopped after a period of several hours and that potentially affected people would be evacuated in much less than 10 hours. Table 7 summarises the radiological consequences of a land transport accident resulting in a release of radioactivity, dependent on the distance of the exposed individual from the accident (effective dose in mSv in the first year after the occurrence of the accident). These doses can be converted to risks to individuals located 100 m from the site of an accident. The results are shown in Table 8. At a distance of 500 m, the doses are about 10 times less.

Table 6: Comparison of the calculated source terms for 10 hour and 1 week release (double lid failure, leak rate ~1 mbar · l/s) with IAEA Transport Regulations release limits for to accident conditions (see TS-R-1, § 656)

Nuclides	Activity inventory for 33 MOX-SFA (Bq)	Maximum source terms for 10 h (Bq)	Maximum source terms for a week (Bq)	Release limits in IAEA Transport Regulations (one week) (Bq)
^{3}H	2.51×10^{14}	6.90×10^{11}	1.10×10^{13}	4.00×10^{13}
^{85}Kr	1.65×10^{15}	9.08×10^{11}	1.53×10^{13}	1.00×10^{14}
^{129}I	1.22×10^{10}	6.71×10^{6}	1.13×10^{8}	Unlimited
^{134}Cs	8.84×10^{15}	2.34×10^{10}	3.93×10^{11}	7.00×10^{11}
^{137}Cs	3.94×10^{16}	1.04×10^{11}	1.75×10^{12}	6.00×10^{11}
^{90}Sr	7.80×10^{15}	2.06×10^{6}	3.46×10^{7}	3.00×10^{11}
^{106}Ru	6.55×10^{15}	1.73×10^{6}	2.91×10^{7}	2.00×10^{11}
^{144}Ce	2.22×10^{15}	5.78×10^{5}	9.87×10^{6}	2.00×10^{11}
^{238}Pu	3.79×10^{15}	1.00×10^{6}	1.68×10^{7}	1.00×10^{9}
^{239}Pu	2.22×10^{14}	5.86×10^{4}	9.85×10^{5}	1.00×10^{9}
^{240}Pu	7.54×10^{14}	1.99×10^{5}	3.34×10^{6}	1.00×10^{9}
^{241}Pu	1.45×10^{17}	3.84×10^{7}	6.45×10^{8}	6.00×10^{10}
^{241}Am	1.89×10^{15}	4.96×10^{5}	8.33×10^{6}	1.00×10^{9}
^{244}Cm	6.55×10^{15}	1.73×10^{6}	2.90×10^{7}	2.00×10^{9}

Table 7: Probabilities of releases as a result of different severity categories of land transport accidents with spent fuel casks (CASTOR type) and their radiological consequences (effective doses in mSv)

Severity category	**BK 4 (single seal failure) Leakage rate £10^{-4} mbar·· l/s**		**BK 5 (double seal failure) Leakage rate £1 mbar·· l/s**	
Probability of radioactivity release	P_{RR} (road) = 1.3×10^{-7} km^{-1}		P_{RR} (road) = 2.8×10^{9} km^{-1}	
	P_{RR} (rail) = 1.1×10^{-8} km^{-1}		P_{RR} (rail) = 2.3×10^{-10} km^{-1}	
Distance (m)	Effective dose in the first year after accident (mSv)		Effective dose in the first year after accident (mSv)	
	Adult	Child	Adult	Child
100	1.6×10^{-3}	2.1×10^{-3}	15.6 (2.4)	20.6 (0.8)
200	7.0×10^{-4}	9.4×10^{-4}	6.8 (0.9)	9.2 (0.3)
500	2.5×10^{-4}	3.4×10^{-4}	2.4 (0.3)	3.3 (0.1)

( ) The figures in brackets represent the more realistic exposure doses to the public based on inhalation doses

Accidents during sea shipment were considered by the IAEA [5]. Experimental and modelling work showed that fire heat fluxes in sea accidents were generally smaller than those of regulatory cask certification fire tests. They also showed that if a ship collision subjects a type B package to crush forces, the magnitude of these forces will be less than or at most comparable with the inertial forces experienced by the cask during the regulatory certification impact test. Therefore, it is not very likely that both seals of the cask would fail in such an accident. The effective doses to an individual caused by the loss of a type B package after a collision at sea into shallow, continental-shelf waters [10] and into deep ocean waters [11] were estimated to be:

- 4×10^{-4} mSv per year for the loss of a package containing high-burn up spent fuel into shallow (200 m) continental-shelf waters;
- 5×10^{-9} mSv per year for the loss of a package into the deep ocean.

Release of fission products to the atmosphere due to a severe collision and spreading of a severe fire to the hold that leads to a double seal failure was also estimated to cause average individual doses of about:

- 0.5 mSv for an accident during a call at a major port;
- 0.2 mSv for people living in urban areas along a coastal sailing route.

These values are lower than the ICRP recommended effective dose limits for members of the public (1 mSv/year) and well below natural background radiation dose rates (2.5 mSv/year global average).

Taking into account the frequency of an accident scenario similar to the severity category BK 5 for land transport accidents, radiological risks to individuals can be estimated per voyage (see Table 9).

Table 8: Risks to individuals located 100 m away from the accident site for land transport[1)] of spent fuel assemblies given in number of fatalities (LCF) per km and per year (A: adult; C: child)

		Risk (conservative)[2)] in LCF		Risk (realistic)[3)] in LCF	
Transport mode		per km	per year	per km	per year
Road	A	2.9×10^{-12}	3.5×10^{-7}	4.5×10^{-13}	5.4×10^{-8}
	C	3.9×10^{-12}	4.6×10^{-7}	1.5×10^{-13}	1.8×10^{-8}
Rail	A	2.4×10^{-13}	1.2×10^{-9}	3.7×10^{-14}	1.8×10^{-10}
	C	3.7×10^{-13}	1.6×10^{-9}	1.2×10^{-14}	6.2×10^{-11}

1) It is assumed that each year five rail transports will be carried out between a Pangea receiving port and the repository – each 1,000 km, i.e. total 5,000 km per year for rail shipments with 24 casks for each shipment. In the case of truck transport on the road, there will be 120 transports per year, i.e. 120,000 km per year for truck transport.

2) With the assumption, that the exposed members of the public stay in the immediate vicinity of the accident site for the whole time (1 year), (i.e. no evacuation of people and no clean-up/remediation of site).

3) With the assumption that people will be evacuated and the site will be cleaned/remediated as soon as possible after the accident (i.e. only inhalation doses are relevant).

Table 9: Radiological consequences to individuals for sea transport accidents with spent fuel

Voyage location	$\mathbf{P_{AC}}$	$\mathbf{P_{BK}}$	$\mathbf{P_{RR}}$**-sea**	**Effective dose (mSv)**	**Individual risk in LCF**	
					per voyage	**per year**
Port	$2 \times 4.0 \times 10^{-5}$	4.0×10^{-9}	3.2×10^{-12}	0.5	1.1×10^{-16}	5.5×10^{-16}
Coastal waters	2.0×10^{-4}	4.0×10^{-9}	8.0×10^{-13}	0.2	1.1×10^{-17}	5.5×10^{-17}
Open ocean	7.0×10^{-5}	4.0×10^{-9}	2.8×10^{-13}	5×10^{-9}	9.4×10^{-24}	4.7×10^{-23}
				Total	1.2×10^{-16}	6.0×10^{-16}

P_{AC}: Accident frequency per voyage (22,000 km)
P_{BK}: Probability of radioactivity release per sea-accident

TRANSFER ACCIDENT RISKS

We estimate that the probability of transfer accidents that can lead to radioactivity release (P_{RR}-transfer) will be about the same order of magnitude or less as for road accidents for the same amount of cask shipment. The risk associated with transfer accidents at the Pangea receiving harbour would thus be about 7×10^{-10} LCF/year for individual members of the public. For transhipment operations at the receiving Pangea harbour, the figure will be lower by several orders of magnitude, taking into account the design of type B packages and the special handling procedures likely to be adopted.

RADIOLOGICAL RISKS OF INCIDENT-FREE TRANSPORTATION

Radiological consequences can potentially occur due to exposure of people to low levels of external radiation in the vicinity of spent fuel casks (0.1 mSv/h at 2 m distance) during normal transportation. The effective dose for a person standing 10 m from a transport travelling at 20 km/h is about 0.025 µSv. This corresponds to an annual risk (of latent cancer fatality) to an individual of 1.7×10^{-9}.

NON-RADIOLOGICAL CONSEQUENCES AND RISKS OF TRANSPORT

The non-radiological consequences of transportation are mainly due to exposures to vehicle exhaust. USDOE [12] estimated these to be:

- **Urban areas:**	1.0×10^{-7} fatality/km for trucks 1.3×10^{-7} fatality/km for trains (diesel locomotives)
- **Suburban and rural areas:**	7.2×10^{-11} fatality/km

However, the transport densities and the number of inhabitants per unit area in the suburban and rural regions of the USA may be significantly higher than in a Pangea repository host country.

CONCLUSIONS

The radiological consequences and the corresponding frequencies of transport accidents have been calculated using conservative assumptions and are considered to be about 1 - 3 orders of magnitude overestimated. Table 10 summarises the main results of this study. It can be seen that rail transport has about two orders of magnitude less accident risks than road transport. Sea transport risks are several orders of magnitude less than land transport risks. To put the figures in Table 10 into an everyday context, Table 11 presents a mixture of voluntary and involuntary risks to which individuals are exposed. The figures are approximate and clearly make various averaging assumptions about the extent to which people take part in activities and where they live. The results of this study indicate:

- Radiological consequences from possible transport accidents with spent fuel are significantly below the permissible exposure limits set in national and international regulations. They are also significantly lower than risks that are commonly regarded as trivial and acceptable to society and far below risks attributable to natural background radiation levels.

- Radiological risks during incident-free transport are 1-2 orders of magnitude higher than radiological risks arising from accidents during land transport of spent fuel and are of the same order of magnitude as the non-radiological risks due to exposure to vehicle exhaust gases.

- Risks of sea transport are several orders of magnitude less than for land transport and can be considered as insignificant compared with land transport accident and other risks.

Table 10: Summary table of radiological and non-radiological risks to individuals

RADIOLOGICAL RISKS (IN LATENT CANCER FATALITIES)		
Risks from transport accidents		
Transport mode	***per km or call***	***per year***
Sea	2.7×10^{-20}	6.0×10^{-16}
Road	$4,5 \times 10^{-13}$	5.4×10^{-8}
Rail	3.7×10^{-14}	1.8×10^{-10}
Risks from transfer accidents at harbour		
Transport activities	***per call***	***per year***
	1.4×10^{-10}	7×10^{-10}
Risks from incident-free transportation during land transport		
Transport activities	***per km***	***per year***
Passive exposure to public (road/rail)	1.7×10^{-9}	1.7×10^{-9}

NON-RADIOLOGICAL RISKS TO THE POPULATION ALONG ROAD/RAIL TRANSPORT ROUTE (FATALITIES)		
	per km	***per year***
Rural areas	$\sim 7 \times 10^{-11}$	$<4 \times 10^{-7}$
Urban areas	$\sim 1 \times 10^{-7}$	5×10^{-4}

Table 11: Risks of voluntary & involuntary activities compared with risks associated with spent fuel transport

Activity, event or hazard*	**Risk per year to an individual (in powers of ten)**	**Rounded risk per year, in decimal form (where 1.0 is a 100% probability of death)**
Using hard drugs	1.5×10^{-2}	0.02
Cancer (all forms)	7.8×10^{-3}	0.008
Smoking 10 cigarettes a day	5×10^{-3}	0.005
Hang Gliding	1×10^{-3}	0.001
Falling (all types)	2.3×10^{-4}	0.0002
Living in average natural radiation background	1.7×10^{-4}	0.0002
Driving a car	1×10^{-4}	0.0001
Level above which risks are generally considered intolerable by society, and requiring definite action to reduce them	1×10^{-4}	0.0001
Accidents at home	8.5×10^{-5}	0.00009
Office work	3.7×10^{-5}	0.00004
Drowning	1.9×10^{-5}	0.00002
Food poisoning	1.2×10^{-6}	0.000001
Level below which risks are generally considered trivial by society, and requiring no action to reduce them further	1×10^{-6}	0.000001
Lightning strike	5×10^{-7}	0.0000005
Typical estimated exposure to possible releases from a deep spent fuel repository in the far distant future	1×10^{-8}	0.00000001
Accident leading to radiation release during a 1000 km rail journey with spent fuel	2.4×10^{-10}	0.0000000002
Accident leading to radiation release during a 20,000 km sea voyage with spent fuel	1.2×10^{-16}	0.0000000000000001

*Additional data taken from [13].

REFERENCES

[1] Black , J H, Chapman, N A, 2001. Siting a High Isolation Radioactive Waste Repository. Technical Approach to Identification of Potentially Suitable Regions Worldwide. Pangea Technical Report PTR-01-01, Pangea, Baden, Switzerland

[2] Tunaboylu K, Playfair A, Nandakumar M, 2001: Waste Transport and Public Safety. Pangea Technical Report PTR-01-03, August 2001, Pangea, Baden, Switzerland

[3] IAEA Regulations for the Safe Transport of Radioactive Materials, 1996. The new designation is TS-R-1 and it is entered into force since July 2001

[4] Saricks CL, Tompkins M M, 1999. State-Level Accident Reates of Surface Freight Transportation: A Reexamination, ANL/ESD/TM-150, The Centre for Transportation Research, Energy System Division, Argonne National Laboratory, April 1999.

[5] Pope R B, Bernard-Bruls X, 1999. Monitoring High-Activity Radioactive Material Transport by Sea, Accident Scenarios and Predicted Responses, Conference on Carriage of Ultra-Hazardous Radioactive Cargo by Sea: Regional Implications and Responses. 18-19 October 1999.

[6] GRS (Gesellschaft für Reaktorsicherheit), 1991. Transportstudie Konrad: Sicherheitsanalyse des Transports radioaktiver Abfälle zum Endlager Konrad, GRS-84, Juli 1991

[7] Miles, J C, Molyneaux, T C K, Dowler, HJ, 1985. Paper No. 14, Analysis of Primary Impact Forces in the Train Crash Demonstation, Papers presented at a Seminar held at the Institution of Mechanical Engineers, UK, on 30.04. and 01.05.1985.

[8] PSE (Projekt Sicherheitsstudien Entsorgung), 1985. Sicherheitsanalyse der Transporte von radioaktiven Materialien für

[9] Fischer L E et al, 1987. Shipping Container Response to Severe Highway and Railway Accident Conditions, NUREG/CR 4829

[10] Tsumune D, Saegusa T, 2000: Dose Assessment for Public by Packages Shipping Radioactive Materials Hypothetically Sunk on a continental shelf. Central Research Institute for Electric Power Industry, Abiko-city, Japan, and Mitsubishi Research Institute, Tokyo.

[11] Watabe N, Tsumune D, Saegusa T, 1996:, An Environmental Impact Assessment for Sea Transport of High Level Radioactive Waste. Central Research Institute for Electric Power Industry, Abiko-city, Japan,

[12] DOE (U.S. Department of Energy), 1995. Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs: Final Environmental Impact Statement, DOE/EIS-0203-F, Office of Environmental Management, Idaho Operations Office, Idaho Falls, Idaho.

[13] Chapman, N. A. & McCombie, C.M., 2001 (book submitted) Safety Principles and Standards for the Geological Disposal of Radioactive Wastes. 256 pps.